Acceleration

Note:
SECTION LEARNING OBJECTIVES

By the end of this section, you will be able to do the following:

- Explain acceleration and determine the direction and magnitude of acceleration in one dimension
- Analyze motion in one dimension using kinematic equations and graphic representations

Section Key Terms

average acceleration	instantaneous acceleration	negative acceleration

Defining Acceleration

Throughout this chapter we will use the following terms: *time*, *displacement*, *velocity*, and *acceleration*. Recall that each of these terms has a designated variable and SI unit of measurement as follows:

- Time: t, measured in seconds (s)
- Displacement: Δd, measured in meters (m)
- Velocity: v, measured in meters per second (m/s)

- Acceleration: *a*, measured in meters per second per second (m/s^2, also called meters per second squared)
- Also note the following:
    - Δ means *change in*
    - The subscript 0 refers to an initial value; sometimes subscript i is instead used to refer to initial value.
    - The subscript f refers to final value
    - A bar over a symbol, such as , means *average*

Acceleration is the change in velocity divided by a period of time during which the change occurs. The SI units of velocity are m/s and the SI units for time are s, so the SI units for acceleration are m/s^2. **Average acceleration** is given by

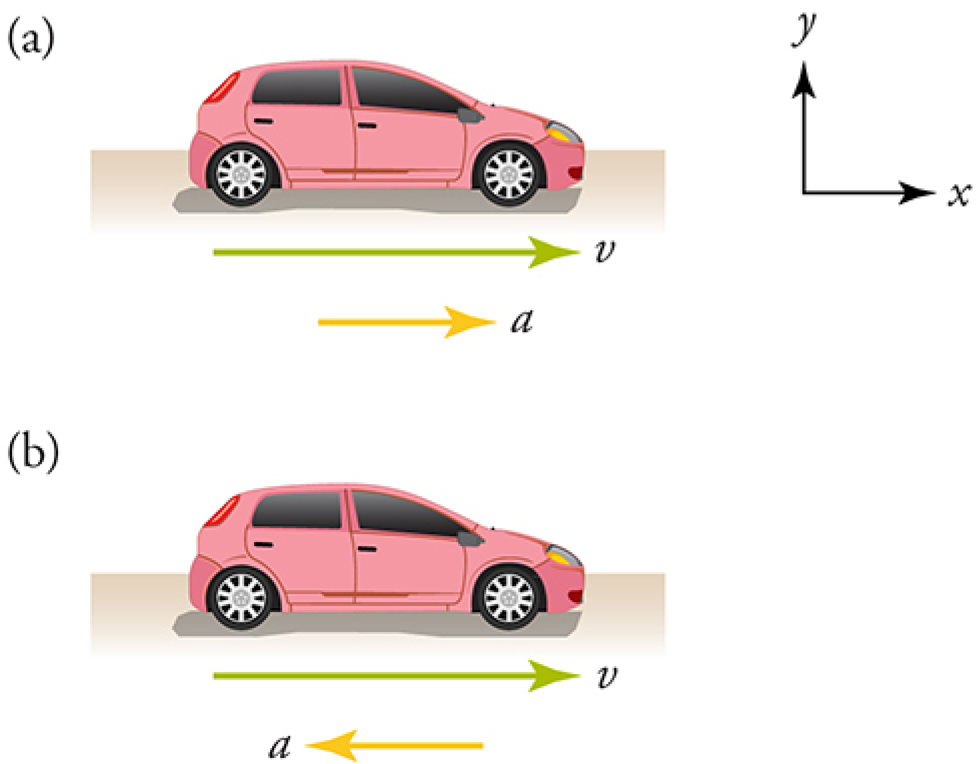
Equation:

Average acceleration is distinguished from **instantaneous acceleration**, which is acceleration at a specific instant in time. The magnitude of acceleration is often not constant over time. For example, runners in a race accelerate at a greater rate in the first second of a race than during the following seconds. You do not need to know all the instantaneous accelerations at all times to calculate average acceleration. All you need to know is the change in velocity (i.e., the final velocity minus the initial velocity) and the change in time (i.e., the final time minus the initial time), as shown in the formula. Note that the average acceleration can be positive, negative, or zero. A **negative acceleration** is simply an acceleration in the negative direction.

Keep in mind that although acceleration points in the same direction as the *change* in velocity, it is not always in the direction of the velocity itself. When an object slows down, its acceleration is opposite to the direction of its velocity. In everyday language, this is called deceleration; but in physics, it is acceleration—whose direction happens to be opposite that of the

velocity. For now, let us assume that motion to the right along the *x*-axis is *positive* and motion to the left is *negative*.

[link] shows a car with positive acceleration in (a) and negative acceleration in (b). The arrows represent vectors showing both direction and magnitude of velocity and acceleration.



The car is speeding up in (a) and slowing down in (b).

Velocity and acceleration are both vector quantities. Recall that vectors have both magnitude and direction. An object traveling at a constant velocity—therefore having no acceleration—does accelerate if it changes direction. So, turning the steering wheel of a moving car makes the car accelerate because the velocity changes direction.

Note:

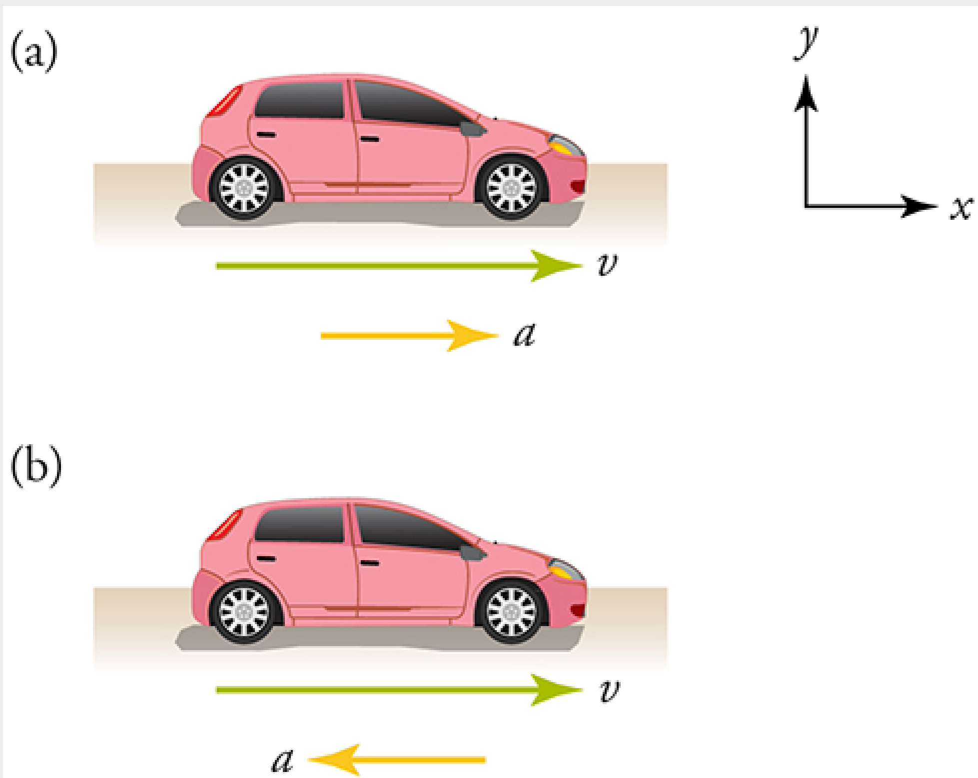
The Moving Man

With this animation, you can produce both variations of acceleration and velocity shown in [link], plus a few more variations. Vary the velocity and acceleration by sliding the red and green markers along the scales. Keeping the velocity marker near zero will make the effect of acceleration more obvious. Try changing acceleration from positive to negative while the man is moving. We will come back to this animation and look at the *Charts* view when we study graphical representation of motion.

https://openstax.org/l/02moving_man

Exercise:

Problem:



Which part, (a) or (b), is represented when the velocity vector is on the positive side of the scale and the acceleration vector is set on the negative side of the scale? What does the car’s motion look like for the given scenario?

a. Part (a). The car is slowing down because the acceleration and the velocity vectors are acting in the opposite direction.
b. Part (a). The car is speeding up because the acceleration and the velocity vectors are acting in the same direction.
c. Part (b). The car is slowing down because the acceleration and velocity vectors are acting in the opposite directions.
d. Part (b). The car is speeding up because the acceleration and the velocity vectors are acting in the same direction.

Calculating Average Acceleration

Look back at the equation for average acceleration. You can see that the calculation of average acceleration involves three values: change in time, (Δt); change in velocity, (Δv); and acceleration (a).

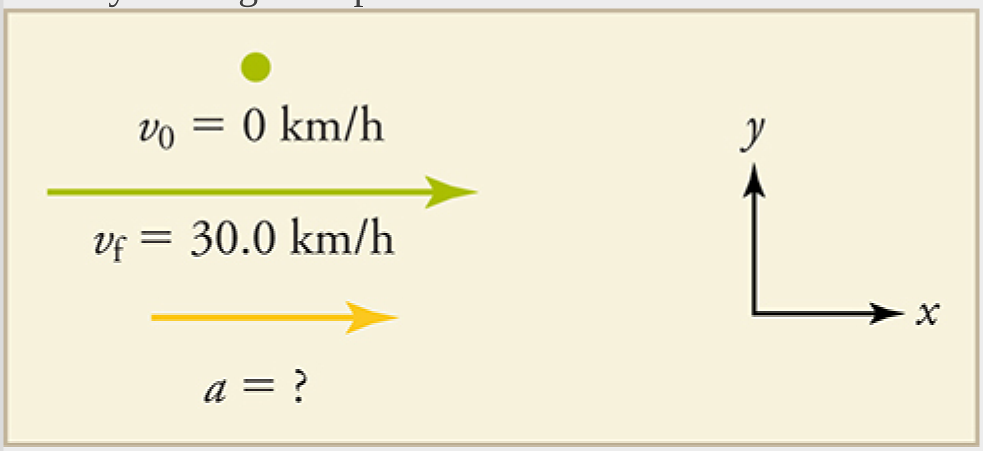
Change in time is often stated as a time interval, and change in velocity can often be calculated by subtracting the initial velocity from the final velocity. Average acceleration is then simply change in velocity divided by change in time. Before you begin calculating, be sure that all distances and times have been converted to meters and seconds. Look at these examples of acceleration of a subway train.

Note:
An Accelerating Subway Train
Exercise:

Problem:

A subway train accelerates from rest to 30.0 km/h in 20.0 s. What is the average acceleration during that time interval?

Note:
Strategy
Start by making a simple sketch.



This problem involves four steps:

1. Convert to units of meters and seconds.
2. Determine the change in velocity.
3. Determine the change in time.
4. Use these values to calculate the average acceleration.

Solution:
Solution

1. Identify the knowns. Be sure to read the problem for given information, which may not *look* like numbers. When the problem states that the train starts from rest, you can write down

that the initial velocity is 0 m/s. Therefore, $v_0 = 0$; $v_f = 30.0$ km/h; and $\Delta t = 20.0$ s.

2. Convert the units.
   Equation:

3. Calculate change in velocity,
   where the plus sign means the change in velocity is to the right.

4. We know Δt, so all we have to do is insert the known values into the formula for average acceleration.
   Equation:

Discussion

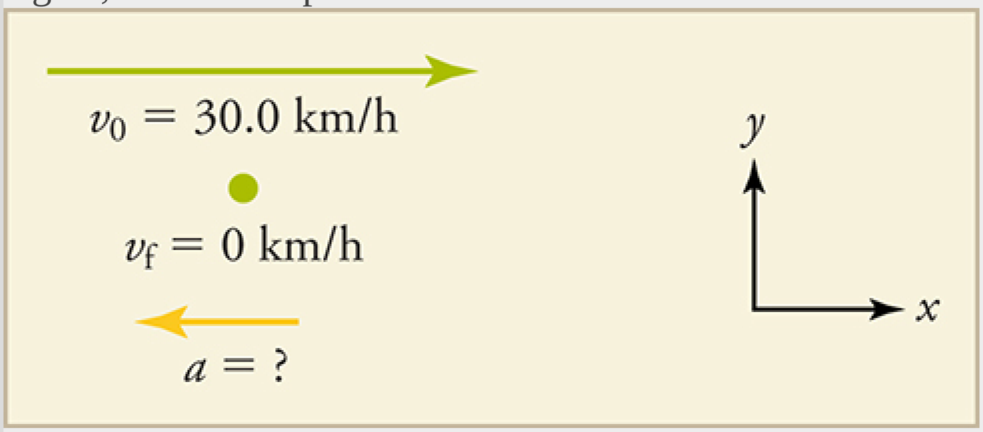
The plus sign in the answer means that acceleration is to the right. This is a reasonable conclusion because the train starts from rest and ends up with a velocity directed to the right (i.e., positive). So, acceleration is in the same direction as the *change* in velocity, as it should be.

Note:
An Accelerating Subway Train
Exercise:

Problem:

Now, suppose that at the end of its trip, the train slows to a stop in 8.00 s from a speed of 30.0 km/h. What is its average acceleration during this time?

Note:
Strategy
Again, make a simple sketch.



In this case, the train is decelerating and its acceleration is negative because it is pointing to the left. As in the previous example, we must find the change in velocity and change in time, then solve for acceleration.

Solution:
Solution

1. Identify the knowns: v_0 = 30.0 km/h; v_f = 0; and Δt = 8.00 s.
2. Convert the units. From the first problem, we know that 30.0 km/h = 8.333 m/s.
3. Calculate change in velocity, where the minus sign means that the change in velocity points to the left.

4. We know Δt = 8.00 s, so all we have to do is insert the known values into the equation for average acceleration.
   Equation:

Discussion

The minus sign indicates that acceleration is to the left. This is reasonable because the train initially has a positive velocity in this problem, and a negative acceleration would reduce the velocity. Again, acceleration is in the same direction as the *change* in velocity, which is negative in this case. This acceleration can be called a deceleration because it has a direction opposite to the velocity.

Note:

- It is easier to get plus and minus signs correct if you always assume that motion is away from zero and toward positive values on the *x*-axis. This way *v* always starts off being positive and points to the right. If speed is increasing, then acceleration is positive and also points to the right. If speed is decreasing, then acceleration is negative and points to the left.
- It is a good idea to carry two extra significant figures from step-to-step when making calculations. Do not round off with each step. When you arrive at the final answer, apply the rules of significant figures for the operations you carried out and round to the correct number of digits. Sometimes this will make your answer slightly more accurate.

Practice Problems

Exercise:

Problem: [link]

Exercise:

Problem: [link]

Exercise:
test: requires context, open ended, figure

Problem: [link]

Exercise:
test: requires context, MC, note

Problem: [link]

Exercise:
test: requires context, MP, iframe

Problem: [link]

Note:
Acceleration
This video shows the basic calculation of acceleration and some useful unit conversions.
https://www.khanacademy.org/embed_video?v=FOkQszg1-j8
Exercise:

Problem: [link]

Exercise:

Problem: [link]

Note:

Measure the Acceleration of a Bicycle on a Slope

In this lab you will take measurements to determine if the acceleration of a moving bicycle is constant. If the acceleration is constant, then the following relationships hold: — —— If , then and —

You will work in pairs to measure and record data for a bicycle coasting down an incline on a smooth, gentle slope. The data will consist of distances traveled and elapsed times.

- Find an open area to minimize the risk of injury during this lab.

- stopwatch
- measuring tape
- bicycle

1. Find a gentle, paved slope, such as an incline on a bike path. The more gentle the slope, the more accurate your data will likely be.
2. Mark uniform distances along the slope, such as 5 m, 10 m, etc.
3. Determine the following roles: the bike rider, the timer, and the recorder. The recorder should create a data table to collect the distance and time data.
4. Have the rider at the starting point at rest on the bike. When the timer calls *Start*, the timer starts the stopwatch and the rider begins coasting down the slope on the bike without pedaling.
5. Have the timer call out the elapsed times as the bike passes each marked point. The recorder should record the times in the data table. It may be necessary to repeat the process to practice roles and make necessary adjustments.
6. Once acceptable data has been recorded, switch roles. Repeat Steps 3–5 to collect a second set of data.

7. Switch roles again to collect a third set of data.
8. Calculate average acceleration for each set of distance-time data. If your result for is not the same for different pairs of Δv and Δt, then acceleration is not constant.
9. Interpret your results.

Exercise:

Problem:

If you graph the average velocity (y-axis) vs. the elapsed time (x-axis), what would the graph look like if acceleration is uniform?

a. a horizontal line on the graph
b. a diagonal line on the graph
c. an upward-facing parabola on the graph
d. a downward-facing parabola on the graph

Check Your Understanding

Exercise:

Problem: What are three ways an object can accelerate?

a. By speeding up, maintaining constant velocity, or changing direction
b. By speeding up, slowing down, or changing direction
c. By maintaining constant velocity, slowing down, or changing direction
d. By speeding up, slowing down, or maintaining constant velocity

Exercise:

Problem:

What is the difference between average acceleration and instantaneous acceleration?

a. Average acceleration is the change in displacement divided by the elapsed time; instantaneous acceleration is the acceleration at a given point in time.
b. Average acceleration is acceleration at a given point in time; instantaneous acceleration is the change in displacement divided by the elapsed time.
c. Average acceleration is the change in velocity divided by the elapsed time; instantaneous acceleration is acceleration at a given point in time.
d. Average acceleration is acceleration at a given point in time; instantaneous acceleration is the change in velocity divided by the elapsed time.

Exercise:

Problem: [link]

Section Summary

- Acceleration is the rate of change of velocity and may be negative or positive.
- Average acceleration is expressed in m/s^2 and, in one dimension, can be calculated using

Key Equations

Average acceleration	

Concept Items

Exercise:

Problem:

How can you use the definition of acceleration to explain the units in which acceleration is measured?

a. Acceleration is the rate of change of velocity. Therefore, its unit is m/s^2.
b. Acceleration is the rate of change of displacement. Therefore, its unit is m/s.
c. Acceleration is the rate of change of velocity. Therefore, its unit is m^2/s.
d. Acceleration is the rate of change of displacement. Therefore, its unit is m^2/s.

Exercise:

Problem: [link]

Exercise:

Problem: [link]

Critical Thinking

Exercise:

Problem: [link]

Exercise:

Problem: [link]

Problems

Exercise:

Problem:

The driver of a sports car traveling at 10.0 m/s steps down hard on the accelerator for 5.0 s and the velocity increases to 30.0 m/s. What was the average acceleration of the car during the 5.0 s time interval?

a. $-1.0 \times 102\ m/s^2$
b. $-4.0\ m/s^2$
c. $4.0\ m/s^2$
d. $1.0 \times 102\ m/s^2$

Exercise:

Problem:

A girl rolls a basketball across a basketball court. The ball slowly decelerates at a rate of $-0.20\ m/s^2$. If the initial velocity was 2.0 m/s and the ball rolled to a stop at 5.0 sec after 12:00 p.m., at what time did she start the ball rolling?

a. 0.1 seconds before noon
b. 0.1 seconds after noon
c. 5 seconds before noon
d. 5 seconds after noon

Test Prep Multiple Choice

Exercise:

Problem: Which variable represents displacement?

a. *a*
b. *d*
c. *t*
d. *v*

Exercise:

Problem:

If a velocity increases from 0 to 20 m/s in 10 s, what is the average acceleration?

a. 0.5 m/s^2
b. 2 m/s^2
c. 10 m/s^2
d. 30 m/s^2

Test Prep Short Answer

Exercise:

Problem:

True or False—The vector for a negative acceleration points in the opposite direction when compared to the vector for a positive acceleration.

a. True
b. False

Exercise:

Problem: [link]

Exercise:

Problem:

How is the vector arrow representing an acceleration of magnitude 3 m/s^2 different from the vector arrow representing a negative acceleration of magnitude 3 m/s^2?

a. They point in the same direction.
b. They are perpendicular, forming a 90° angle between each other.
c. They point in opposite directions.
d. They are perpendicular, forming a 270° angle between each other.

Exercise:

Problem:

How long does it take to accelerate from 8.0 m/s to 20.0 m/s at a rate of acceleration of 3.0 m/s^2?

a. 0.25 s
b. 4.0 s
c. 9.33 s
d. 36 s

Test Prep Extended Response

Exercise:

Problem: [link]

Exercise:

Problem:

A car accelerates from rest at a stop sign at a rate of 3.0 m/s^2 to a speed of 21.0 m/s, and then immediately begins to decelerate to a stop at the next stop sign at a rate of 4.0 m/s^2. How long did it take the car to travel from the first stop sign to the second stop sign? Show your work.

a. 1.7 seconds
b. 5.3 seconds
c. 7.0 seconds
d. 12 seconds

Glossary

average acceleration
: change in velocity divided by the time interval over which it changed

instantaneous acceleration
: rate of change of velocity at a specific instant in time

negative acceleration
: acceleration in the negative direction